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Advanced Treatment of Peat Wastewaters

for

Supply and Services Canada
Ottawa, Ontario

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TABLE OF CONTENTS

	Page No.
SUMMARY	v
RÉSUMÉ	vii
2. INTRODUCTION	1
3. EQUIPMENT DESCRIPTION	7
4. ANALYTICAL AND SAMPLING TECHNIQUES	13
5. PILOT SYSTEM OPERATION	14
5.1 Production of Wet Oxidized Peat Filtrate	14
5.2 Anaerobic Fluidized Bed Operation	14
6. ANALYTICAL RESULTS	20
7. DISCUSSION	38
7.1 Start-Up	38
7.2 Mesophilic Operation	38
7.3 Thermophilic Operation	39
7.4 Colour Adsorption	40
7.5 Ammonia Stripping	41
8. CONCLUSIONS	43
9. RECOMMENDATIONS	44
REFERENCES	45

TABLE OF CONTENTS (Contd.)

		Page No.
APPENDIX	A - Wetox(R) Continuous Flow Pilot Plant	47
	B - Raw Data	59
FIGURE	1 - Fluidized Bed	12
	2-13 -	23-34
TABLE	1 - Operating Conditions	19
	2 - Wet Oxidized Peat Filtrate Characteristics	21
	3 - Summary of Anaerobic Fluidized Bed Results	22
	4 - Gas Analysis	35
	5 - Colour Adsorption Results	36
	6 - Ammonia Stripping Results	37

Advanced Treatment of Peat Wastewaters
(Proposal P-4454/G)

to

Supply and Services Canada
Ottawa, Ontario

1. SUMMARY

The thermophilic anaerobic digestion of wastewater from thermal processing and dewatering of fuel grade peat by use of an expanded bed reactor using granular activated carbon was proposed by Ontario Research.

The peat filtrate was characterized as a deeply coloured, acidic liquid with high concentrations of soluble organic matter and ammonia. Results of the treatment program for peat wastewater showed successful removal of colour, COD and BOD. Colour removal was considerably better than that experienced with other anaerobic treatment systems which did not employ activated carbon. The useful life of the activated carbon was greatly extended over that predicted from standard adsorbent isotherm studies.

Ammonia stripping within the reactor or of the recycle liquor without pH adjustment was determined to be impractical.

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Méthode perfectionnée de traitement
des eaux de tourbe usées
(Proposition P-4454/G)

présentée à

Approvisionnements et Services Canada
Ottawa (Ontario)

1. RÉSUMÉ

L'Ontario Research a proposé de traiter les eaux usées, provenant du traitement thermique et de l'égouttage de la tourbe de qualité combustible, par digestion anaérobie thermophile dans un réacteur à lit expansé en présence de charbon actif granulaire.

Le filtrat ainsi obtenu était un liquide foncé et acide présentant des concentrations élevées de matières organiques solubles et d'ammoniac. Les résultats du programme de traitement indiquaient qu'il y avait eu décoloration et diminution efficaces de la DCO et de la DBO. Le degré de décoloration était considérablement plus élevé que celui observé avec d'autres systèmes de traitement anaérobie n'utilisant pas de charbon actif. La durée de vie du charbon actif était beaucoup plus longue que la durée prévue à partir des isothermes d'adsorption.

L'élimination de l'ammoniac dans le réacteur ou dans la solution de recyclage n'était pas praticable sans un réglage du pH.

2. INTRODUCTION

Peat is a potentially valuable indigenous fuel resource in Eastern Canada.

Peat bogs cover approximately 12% of Canada, particularly in the provinces of Ontario, Quebec, New Brunswick and Newfoundland. The exploitation of these vast potential sources of energy will require new technology in wet mining and dewatering in order to recognize peat as a fuel resource. Fuel grade peats have a very high moisture content as they are often found in flooded bog or muskeg regions. To obtain a fuel resource, the moisture content of the peat must be reduced from 95% to 50% or less. This will involve the removal of up to 18 tons of water per ton of dry peat product.

The environmental impact of the large volumes of wastewater produced, combined with the economic viability of peat dewatering, requires further investigation.

Various approaches have been proposed to remove the water from fuel grade peat. These have included:

- Mechanical dewatering using filter presses, etc.
- Thermal drying of mechanically dewatered peat
- Thermal dewatering through external heating of the peat slurry and subsequent filtration
- Chemical dewatering through partial wet air oxidation.

Mechanical dewatering is very difficult with fuel grade peat and reducing the water content below about 70% is not practical. The product of mechanical dewatering, therefore, requires further drying before it can be successfully utilized as a fuel.

A number of approaches to changing the gel-like structure of the fuel grade peat through "heat treatment" of the fuel peat slurry as mined from the bog are being currently investigated. These approaches fall into two major subdivisions:

- External slurry heating (wet carbonization)
- Partial wet air oxidation

Both these approaches involve raising the temperature of the peat slurry to about 200°C, at which temperature chemical reactions occur which result in some solubilization of the organic material and in a more readily dewaterable solid product. In the case of wet carbonization, these chemical reactions will involve basically the hydrolysis of the fuel peat, while, in the case of partial wet air oxidation, the hydrolysis reactions will be augmented with oxidation reactions. There are advantages in the wet air oxidation approach in that the heat is produced in the reactor, through oxidation of a part of the peat feed. The unit can be designed to operate autothermally, thus eliminating the requirement for external fuel for the process. The wet oxidation and wet carbonization processes both produce strongly acidic and coloured effluents with high levels of Biochemical Oxygen Demand (BOD), ammonium and phenolic compounds.

Previous work by Ontario Research (Sheppard et al, 1982) on partial wet air oxidation of peat slurries showed that, between 10 and 25% of the total Chemical Oxygen Demand (COD) associated with the feed peat is solubilized during the process, with 70 to 90% of the peat solids being recovered as a solid fuel product with less than 50% moisture content. Starting with a 10% peat slurry (approximately 15% COD), the resulting wastewater, in the case where 20% of the original COD is solubilized, would have a COD of 3%. This is probably a maximum concentration that would be anticipated in the filtrate/pressate from partial wet air oxidation, and it could be much lower; say for a 5% peat

slurry (7.5% COD) with 10% solubilized, the resultant wastewater would have a COD of about 0.75%. Organically bound nitrogen in substrate materials is converted mainly to ammonia by wet oxidation. Continuous partial wet oxidation trials with Northern Ontario peat (1.7% TKN dry weight) showed 50 to 90% of the original peat nitrogen to be present in the effluent. Ammonia accounted for 76% of the TKN.

Preliminary biological treatability work on pressate from the partial wet oxidation of peat was conducted as a portion of the previous Ontario Research study (Sheppard et al, 1982). Anaerobic digestion was shown to be particularly promising for the removal of carbonaceous material in the pressate. Treatment in anaerobic filters under mesophilic conditions (35^{o}C) achieved 75% and 79% conversion efficiencies for COD and BOD_5 removal respectively. The organic material was converted to a gas containing 75% methane. Successful organic loading rates for the anaerobic filters were limited to 1 kg COD per day for each m^3 of reactor volume during the study. Ammonia toxicity was the likely explanation for this modest maximum loading rate.

In conventional mesophilic anaerobic digestion, ammonia is reported to have no adverse effects in the range of 200 to 1500 mg/L, expressed as nitrogen (McCarty and McKinney, 1961). The free ammonia species has been identified as the cause of ammonia toxicity, and, at 150 mg/L, is toxic to methanogens. A pronounced lag phase has been reported by some workers (van Velsen and Lettinga, 1979, and Melbinger and Donnellon, 1971), when digested sewage sludge was employed as the inoculum. These same studies have shown that, after a suitable acclimation period, total ammonia-nitrogen concentrations as high as 3,000 mg/L could be tolerated with adequate pH control.

Aerobic polishing of the anaerobic filter effluent (by extended aeration) was shown to reduce BOD_5 levels to less than 50 mg/L, and, after an acclimation period, to accomplish near complete nitrification of

the ammonia. The aerobically treated wastewater did, however, contain a high level of refractory COD (over 1,000 mg/L) and a significant concentration of nitrate-nitrogen (over 500 mg/L). The effluent was also highly coloured [which was likely related to the refractory COD] (Sheppard et al, 1982).

Coupled anaerobic/aerobic treatment of peat wet oxidation pressate has been demonstrated to be effective for the removal of BOD_5 (Sheppard et al, 1982). Advanced treatment of the wastewaters would be required before discharge to surface waters (or sanitary sewers in some localities). A treatment scheme has been developed to address the soluble organic material, ammonia and high colour content of wet oxidized peat pressate. The process combines thermophilic anaerobic digestion in an expanded bed reactor, granular activated carbon (GAC) adsorption (GAC also serves as a support media for the expanded bed), and ammonia stripping.

The beneficial role of activated carbon in an expanded bed for the mesophilic anaerobic digestion of phenolic wastewaters has been reported (Khan et al, 1982). That work compared similar reactors using activated carbon and anthracite, and found that the former media provided superior performance. More recent work employing a synthetic coal gasification wastewater showed that activated carbon facilitated the anaerobic digestion of the otherwise toxic wastewater (Suidan et al, 1983). Individual monohydric phenolic compounds were found to exhibit breakthrough curves typical for carbon adsorption during the initial stage of work, followed by their rapid decrease after a period of acclimation. Activated carbon adsorption capacity was shown to have been reduced due to the presence of biological growth. However, after acclimation, the adsorptive capacity has been shown to improve (Suidan et al, 1983) and a steady-state situation, wherein no significant renewal of carbon would be required, has been predicted (Suidan et al, 1981).

Anaerobic digestion serves both to remove organic material from the peat pressate and to raise the pH of the pressate through the removal of organic acids. Thus, the process reduces the need for chemical addition to adjust pH. Elevated pH is required to strip ammonia from aqueous solution. Operation of the digester at thermophilic temperatures also aids in reducing the demand for addition of base. This is because the endothermic conversion of ammonium to ammonia is thermodynamically favoured by increased temperature and, hence, significant free ammonia is present. Higher temperatures also increase the volatility of ammonia, which results in more efficient ammonia stripping. The temperature of pressate from wet oxidized peat is variable up to 200°C, depending upon the efficiency of heat exchange with raw peat feed. The volatility of ammonia, in aqueous solution, as indicated by the Henry's Law constant, is empirically related to temperature by the following equations (Ip et al, 1978):

$$P = MX$$

$$M = 0.36\, e^{0.53T}$$

where, P = Vapour partial pressure
X = Liquid mole fraction
M = Henry's Law constant
T = liquid temperature, °C

Operating an anaerobic digester at thermophilic, rather than mesophilic conditions, would be expected to raise the ammonia vapour pressure by approximately four times.

Temperature also influences the distribution of ammonia nitrogen and ammonium ion. The dissociation product for ammonia to ammonium at 20°C (K_{20}) is 5×10^{-10} (EPA, 1975). At mesophilic and thermophilic

conditions, the values are 3.9×10^{-9} (K_{35}) and 8.1×10^{-8} (K_{60}) respectively (values estimated by the Gibbs-Helmholtz equation). One result of this is that, in thermophilic anaerobic digestion, a greater proportion of ammonia is present in the unionized form, and, thus, the process is more sensitive to ammonia toxicity (van Velsen and Lettinga, 1979). Operation of a thermophilic anaerobic digester treating a high ammonia wastewater requires rigorous control of pH at a sufficiently low value, ammonia removal, or both.

It is notable that, while ammonia present in wet oxidized peat pressates is undeniably problematic, it also represents a potential revenue source. On the basis of a 100 wet tonne per day peat processing operation, methane recovery would produce about $60/d in fuel value and ammonia recovery of about $40/d in fertilizer product value. [Methane value based on 15% solubilization of peat with COD/TS ratio of 1.5 and 75% conversion to methane. Natural gas valued at $0.10/$m^3$. Ammonia value based on 2% TKN in peat with recovery of 75% as ammonia. Ammonia valued at $214/tonne].

It was the objective of this research to investigate the efficacy of thermophilic anaerobic treatment of peat pressate with simultaneous colour removal and ammonia stripping.

3. EQUIPMENT DESCRIPTION

Fluidized Bed Reactor

The fluidized bed was constructed in two sections. The lower section was a 10 cm (4-inch) diameter, 2 metre (6-foot) clear PVC column at the bottom of which was a conical PVC part mounted and sealed using silicone sealant. At the top of this column was another acrylic column 15 cm (6 inches) in diameter and approximately 1.3 metres (4 feet) in height. These two columns were sealed together by PVC reducing coupling (Figure 1). At the top of the second section, a PVC flange was installed and sealed with silicone. All of the valves were PVC ball valves and all of the pipes and tubing were either of PVC, tygon, reinforced nylon or stainless steel.

Differential Pressure Gauge and Orifice Plate

The differential pressure gauge Model 1506, DG Series, was supplied by Cameron Products and was employed to monitor recycle flowrate. The gauge operated on the basis of the difference in pressure across the 9.5 mm (3/8") orifice plate installed in the recycle line.

Gas Meter

The gas meter, Model P 181, was manufactured and supplied by Triton Electronics Ltd. in England. The battery powered gas meter was employed to measure total gas evolution from the fluidized bed reactor.

Pumps

Recycle Pump - The recycle pump was a Ramoy Progressing Cavity Pump, Series 332.

Peat Waste Feed Pump & Timer - The feed pump was a peristaltic Masterflex Cole Parmer pump plugged directly into an OMRON Flip-Flop Timer. The timer was set so that the pump would deliver the nutrients and peat waste every 20 minutes for 60 seconds. The pump delivered feed into the recycle line.

Chemical Pumps - The 'piston type' chemical feed pumps, Models 12701-11, made by Precision Control Products were used to inject the acid and base into the recycling liquid as required to adjust reactor pH.

Heating Coil

Two heating coils were used during the course of the study, both manufactured and supplied by Pyrotenax. The first heating coil used, code named Model Dale, enabled the liquid phase of the operating system to maintain a mesophilic temperature of 35°C. The second heating coil, Model D-22S2-825, replaced the first coil and enabled the temperature of the system to be maintained at 55°C. The 20-foot long coils were wrapped around a stainless steel pipe section in the continuous recycle line (see Figure 1).

pH Electrode & Transmitter

The pH electrode, Model 9201, was supplied by Presto-Tek. The electrode was installed directly into the recycle line (see Figure 1). The electrode transmitted a low voltage signal to a pH transmitter, Model 422I, supplied by Presto-Tek. The transmitter had a continuous digital display and could be manually adjusted for temperature.

Temperature Probe

The temperature probe was a standard industrial thermocouple, Type K, supplied by OMEGA. The base metal thermocouple was made of chromel-alumel.

Digital/Analogue Converter & Process Control System

The process control system consisted of the following elements:

Taurus One 280A microprocessor - to contain the system logic.

Osborne Personal Computer - to hold the controlling Basic program and to serve to display system outputs on the status of the process and to adjust process control set points.

Analogue/digital converter - to convert Thermocouple and pH meter signals to digital signals and to actuate chemical feed pumps and heater.

Topas Power Maker Model 84472 - to provide uninterrupted power supply to process controller and computer.

The recycling liquid was dispersed through the expanded granular carbon bed which was fluidized to the full height of the 10 cm diameter lower section. In the upper section, recycling liquid passed through either the overflow trap or returned through the recycle system. The overflow was collected or discharged to the drain. The recycling liquid was passed directly to the recycle pump inlet.

Discharge from the pump was passed through a stainless steel section of tubing wrapped with a heating coil. A thermocouple that monitored temperature was situated directly above the stainless steel

tube system. An air trap was installed after the heat exchanger loop to allow for any accumulated air to vent. The peat filtrate feed and standard acid (1N HCl) and base (1N NaOH) were added before the in-line pH probe. The recycling liquid then passed through the orifice plate which enabled the measurement of flows. The pressure gauge installed at the base of the column was a means of indicating flow. In the event of the collapse of the expanded bed in the column, the pressure at this gauge would register higher than normal and the fluidized bed by-pass would be used to take the load off the pump until the situation was remedied.

Peat Wet Oxidation

Peat was wet oxidized in a 50-litre (36-litre active volume) Wetox(R) reactor. The four stage autoclave is described in Appendix A.

Ammonia Stripping

A 9.5 cm diameter, 28 cm long column packed with 8 mm Rashig rings was used to conduct bench scale ammonia stripping studies. The column was maintained at constant temperature by immersing in a water bath. Liquid was pumped to the top of the column by way of a peristaltic pump. Nitrogen gas entered the bottom of the column from a compressed gas cylinder. Gas flow was measured by rotameter.

Adsorption Isotherm Tests

Standard adsorption isotherm tests were conducted using various amounts of Calgon Filtersorb 300 granular activated carbon. The tests were conducted at room temperature and, using 100 mL of solution, vigorously agitated on a Multistir apparatus using magnetic stirring

bars. Samples were withdrawn after one hour, filtered and the colour intensity measured. (A preliminary test was conducted to ensure that the carbon adsorption was effectively complete within the one hour period).

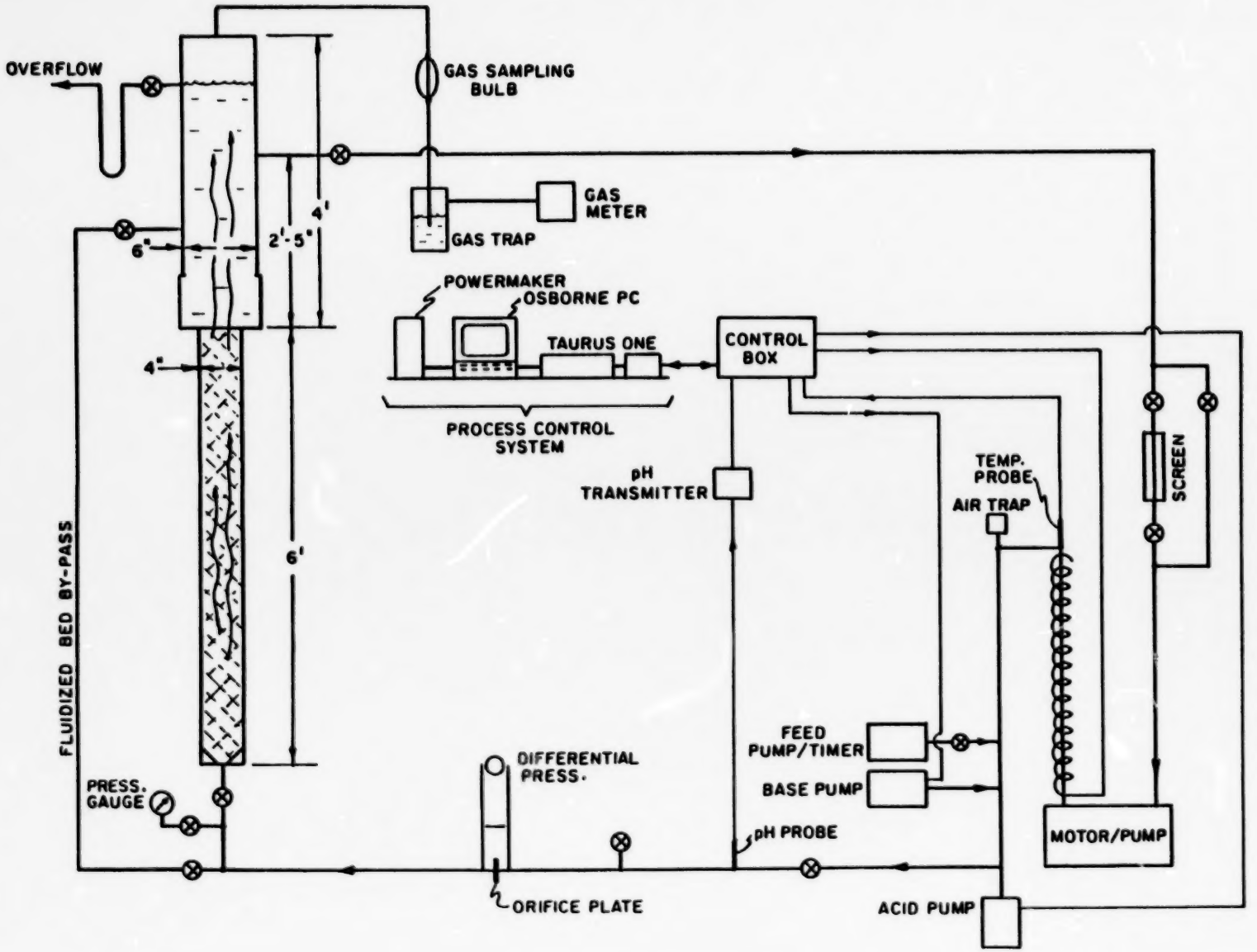

FIG.1 FLUIDIZED BED

4. ANALYTICAL AND SAMPLING TECHNIQUES

Digester effluent was collected at the digester overflow line for several hours and then the recycle sample was withdrawn from a valve in the recycle line. The influent was sampled directly from the peat feed storage container.

In the later stages of the program, sampling was reduced from 5 to 3 days per week with no deletion of any monitored parameter.

Gas analysis was performed intermittently once steady state digester operation had been achieved. A gas sample bulb was installed directly in the digester gas line. A gas trap (which also served as an impinger) and gas meter were also installed in the gas line.

The methods used to measure COD, BOD_5, TSS, VSS, TS and TVS, ammonia, TKN, alkalinity, total volatile acids, true colour, oil and grease, and phenol were all performed in accordance with Standard Methods 16th Edition (WPCF, 1985). The analyses were performed within the same day, or the samples were appropriately preserved and stored.

The gas analysis was performed by gas chromatography (GC) using a Varian Model 1400 and Varian Model 20 recorder. The standard gas mixture was a Scott Specialty Gas, supplied by Supelco. The stainless steel column was packed with a Carbosieve S-II type packing. The analysis followed the given GC operating parameters specific to the column with a few minor alterations. The extraction of the sample gas from the sample bulb was performed by pressurizing the bulb with water, forcing the sample gas into the GC sample loop.

5. PILOT SYSTEM OPERATION

5.1 Production of Wet Oxidized Peat Filtrate

Peats from Barrington, Nova Scotia, and Parry Sound, Ontario, were processed by wet oxidation. The wet oxidation enhanced the dewaterability of the peat.

Peat slurry to the process was homogenized using a recirculating Mazerator Moyno pump and brought to a solids content of approximately 8%. The peat slurry was transferred to the reactor at 1.2 L per minute via a heat exchanger. The peat was then injected into the Wetox$^{(R)}$ reactor, where, in the presence of oxygen and water, the peat was partially oxidized and held at a reaction temperature of approximately 200^{o}C. Air was injected into the first two stages of the reactor only.

Both the hot liquid effluent and the vapour phase (consisting of steam, volatile residues, and non-condensible gases) from the reactor were passed countercurrently through a heat exchanger with the influent slurry.

Cooled liquid and condensed vapour effluents were combined after collection. This mixture was then dewatered using 15 cm Buchner funnels with No. 1 Whatman filter paper.

5.2 Anaerobic Fluidized Bed Operation

Digester start-up involved the following activities:

(1) activated carbon addition to the column
(2) calibration of the gas meters
(3) calibration of the pH transmitter

(4) inputting pH and temperature set points on the computer
(5) collection and pumping in of the 'seed'
(6) calibration of the variable speed recycle pump
(7) installation of the orifice plate.

Approximately 8.2 L (1.0 metre depth) of activated carbon Calgon Filtersorb 300 was added to the column which was then filled with water. The Ramoy recycling pump was then calibrated to determine the approximate flowrate to expand the carbon bed fluidization to a height of 2 metres. The flow rate of approximately 9 L/min (2 Igpm) was required to fluidize the carbon bed.

The column was seeded with primary anaerobic digester sludge from a local sewage treatment plant. Approximately 28 L was required to bring the system up to operating level.

The initial set points were given as follows:

Base Pump pH	Low	7.1
	High	7.2
Acid Pump pH	Low	7.7
	High	7.9
Temperature ^{o}C	Low	28.5
	High	31.5

The column was fed several litres a day of anaerobic digester sludge for approximately three weeks. The seeding was terminated and the peat dewatering wastewater (Nova Scotia) was introduced to the system. The initial loading rate was 1 $kg/m^3.d$ based on the empty volume of the lower section of the reactor (approximately 15 L). The peat filtrate was supplemented with phosphate (to ensure a minimum

BOD:N:P ratio of 100:5:1) and with 50% methanol (on a COD basis). As the COD loading increased, the portion of peat wastewater increased and the amount of water required to dilute decreased. The total prepared peat feed of approximately 15 L/day was maintained throughout the program, giving a retention time of about one day in the lower section of the reactor based on empty bed volume.

The temperature of the column was started between 28.5°C and 31.5°C. Environmental conditions during the winter did influence the column temperature, especially during weekends when the building temperature was unexpectedly reduced. Both the column and heating coil required re-insulation to increase the temperature to obtain a consistent operating temperature of 35°C by day 10.

At the end of 89 operating days, methanol supplementation to the feed was discontinued. Gas production was monitored daily and gas quality measured periodically. It became apparent that the existing heating coil was not capable of increasing and maintaining the digester temperature to thermophilic levels. A new coil was installed on operating day 93 and the temperature was steadily increased over a period of 6 weeks to reach a thermophilic temperature of 55°C on operating day 146. Throughout the program, the COD loading of the column was incrementally increased reaching near 5 kg COD/m^3.d by the time the project was terminated. Table 1 summarizes the operating parameters throughout the program.

Nova Scotia peat was discontinued and Parry Sound peat was used as a source of wet oxidized peat filtrate feed starting on operating day 118.

The system suffered shut-downs periodically. On one occasion, the pump motor controller malfunctioned, which caused the bed to fluidize to a height at which the granulated carbon passed through the recycle

line and into the pump. This caused extensive damage to the stator and rotor in the pump, and transformed the granular bed into powdered activated carbon. Occasionally the pump lost its prime as a result of gas accumulation in a pocket in the recycle line.

During a sustained power failure, the pH controller malfunctioned and it triggered continuous addition of 1N NaOH. This malfunction was caused by a fire in an electrical substation. Normally the Topaz Powermaker permitted the system to quickly recover from minor power interruptions without loss of controller operation. However, this one power failure exceeded the acceptable duration for the battery supply, and hence, the computer program was lost. When power was recovered, the base pump resumed operation without being controlled and, hence, system pH increased dramatically. The treatment efficiency was adversely affected; however, normal operation was re-established within 20 days.

On a separate occasion, all of the peat feed was added at once due to a pump timer malfunction. The pump continued to operate, injecting atmospheric air into the recycling line and, ultimately, the operating column.

Problems with the column were noticed by such indicators as abnormal temperature, pH, pressure (pressure gauge below the column) or flow meter readings.

Refluidization of the activated carbon bed after the several process failures was often problematic. Techniques employed to refluidize were surging of the recycle line by quick valve changes, insertion of a long rod to break up the bed, and injecting compressed nitrogen gas into the bottom of the column.

Another operating problem which was experienced was frequent leaks in, and failure of the Triton gas meters. A consequence of this was an overall unreliability of gas production results.

TABLE 1 - Operating Conditions

Date	Operating Day	Target COD Loading* kg COD/m^3.d	Operating Temperature
Start to Dec. 17	1 - 35	1.0	35°C
Dec. 19 to Dec. 28	37 - 45	1.5	35°C
Dec. 30 to Feb. 14	47 - 93	1.75	35°C
Feb. 15 to Feb. 25	94 - 104	3.5	35°C
Feb. 26 to April 8	105 - 146	3.5	ΔT
April 10 to April 22	148 - 160	3.5	55°C
April 24 to May 13	162 - 181	4.5	55°C
May 15 to June 13	183 - 212	5.0	55°C

*Actual loading rates varied according to wet oxidized peat filtrate COD concentration

ΔT - Temperature Transition

6. ANALYTICAL RESULTS

Table 2 shows the average characteristics of filtrate discharged from the dewatering by wet air oxidized peat. Table 3 is a summary of results obtained during the operation of the anaerobic fluidized bed. Appendix A contains a listing of raw data.

Figures 2 through 13 graphically summarize the influent and effluent data for the fluidized bed.

Table 4 shows the average composition of gases evolved from the anaerobic digester.

Tables 5 and 6 summarize the results of activated carbon adsorption and bench scale ammonia stripping tests.

TABLE 2 - Wet Oxidized Peat Filtrate Characteristics

		Nova Scotia	Parry Sound	Average
pH		3.13	3.13	3.13
Colour,	Hazen Units	6,400	6,717	6,559
TP,	mg/L	10.7	17.0	13.9
COD,	mg/L	11,325	14,250	12,788
BOD,	mg/L	6,653	6,542	6,598
TS,	mg/L	8,150	10,025	9,088
TVS,	mg/L	6,822	9,023	7,923
TSS,	mg/L	14	29.2	21.6
TVSS,	mg/L	12	23.6	17.8
Alk,	mg/L $CaCO_3$	0.2	0	0.1
TV Acids,	mg/L	2,485	2,663	2,574
NH_3-N,	mg/L	357	443	400
TKN,	mg/L	543	580	562

TABLE 3 - Summary of Anaerobic Fluidized Bed Results

Operating Day		COD mg/L	BOD mg/L	Volatile Acids mg/L	NH_3-N mg/L	TKN mg/L	TSS mg/L	VSS mg/L
1- 35	Influent	3670	824	123	553	1350	-	-
	Effluent	2790	255	28	309	630	-	-
37- 45	Influent	2830	840	129	51	67	-	-
	Effluent	974	65	45	56	84	-	-
47- 93	Influent	1590	1020	168	31	46	2.8	2.8
	Effluent	907	197	114	27	42	212	120
94-104	Influent	3870	2400	920	128	181	5.7	5.6
	Effluent	1500	795	570	100	118	470	270
105-146	Influent	3980	1450	748	116	164	11.8	12.0
	Effluent	1550	704	567	110	133	267	116
148-160	Influent	3870	1200	685	107	157	9.0	7.6
	Effluent	1580	608	480	118	142	225	143
162-181	Influent	4840	2090	853	142	204	7.6	6.5
	Effluent	2320	866	830	139	174	486	270
183-213	Influent	4290	1320	756	124	183	5.7	5.1
	Effluent	1940	549	476	135	179	379	214

FIGURE 2

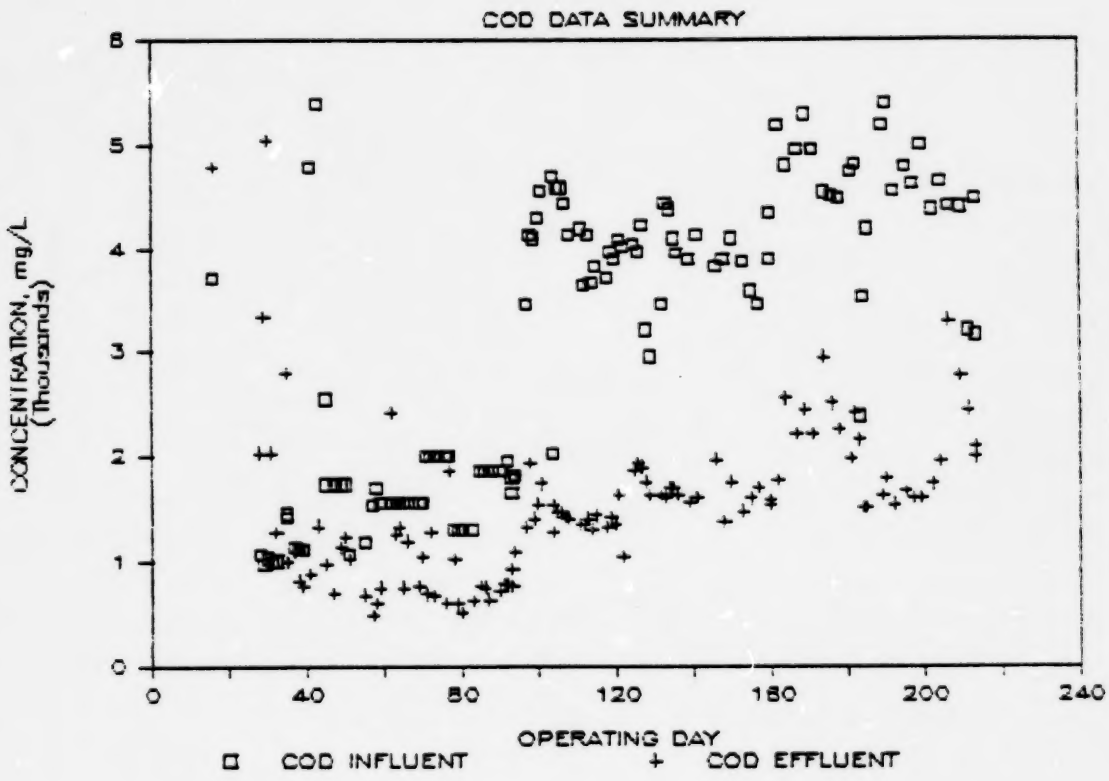
COD DATA SUMMARY
CONCENTRATION, mg/L (thousands)
0
1
2
3
4
5
6
0
40
80
120
160
200
240
OPERATING DAY
COD INFLUENT
COD EFFLUENT

FIGURE 3

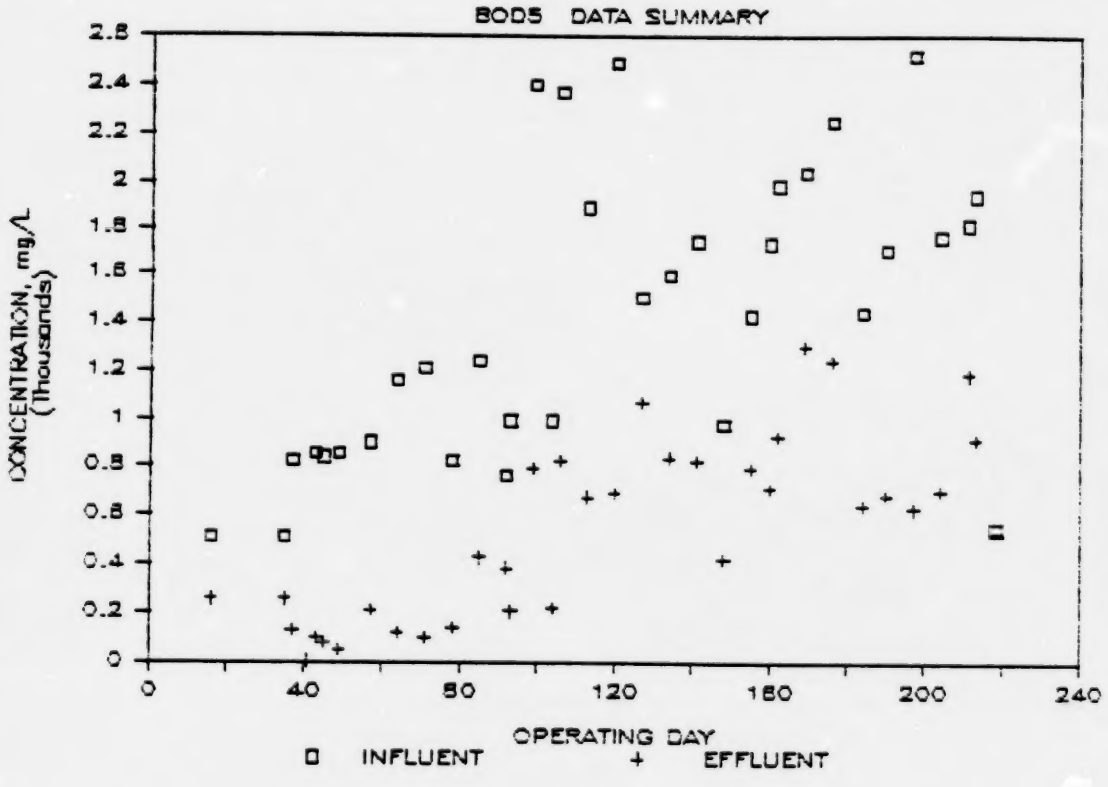
BOD5 DATA SUMMARY
CONCENTRATION, mg/L
(Thousands)
2.8
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
40
80
120
160
200
240
OPERATING DAY
INFLUENT
EFFLUENT

FIGURE 4

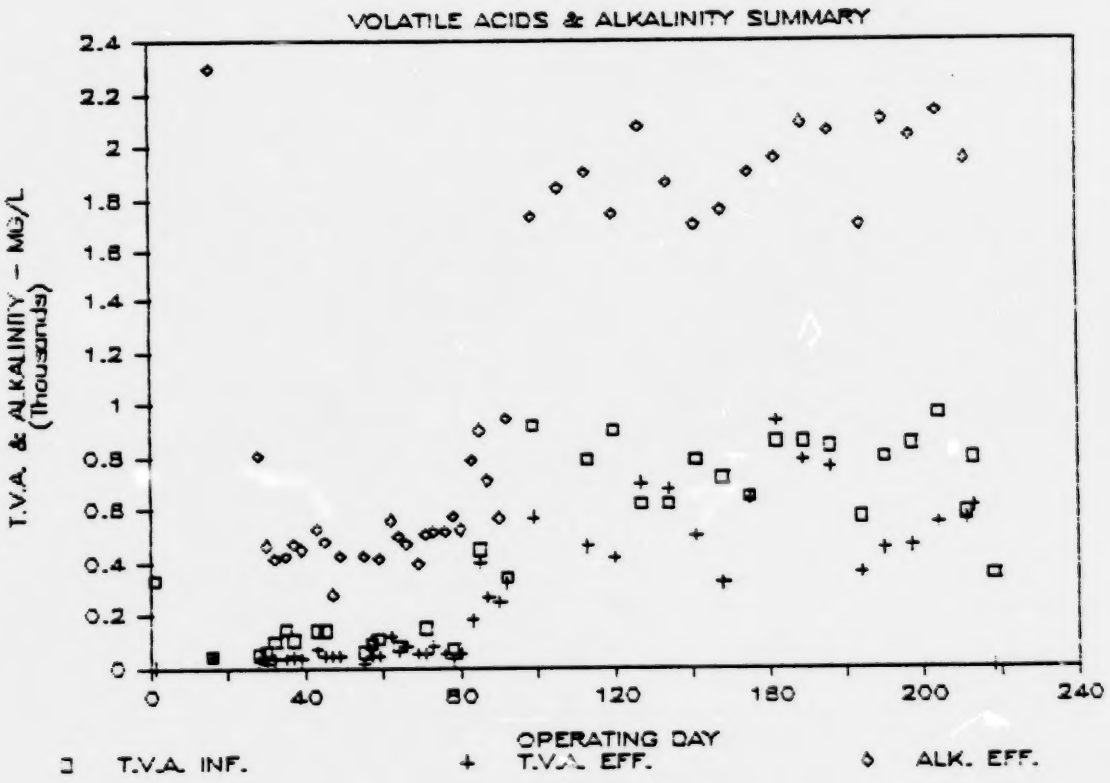
VOLATILE ACIDS & ALKALINITY SUMMARY
T.V.A. & ALKALINITY - MG/L (Thousands)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
40
80
120
160
200
240
OPERATING DAY
T.V.A. INF.
T.V.A. EFF.
ALK. EFF.

FIGURE 5

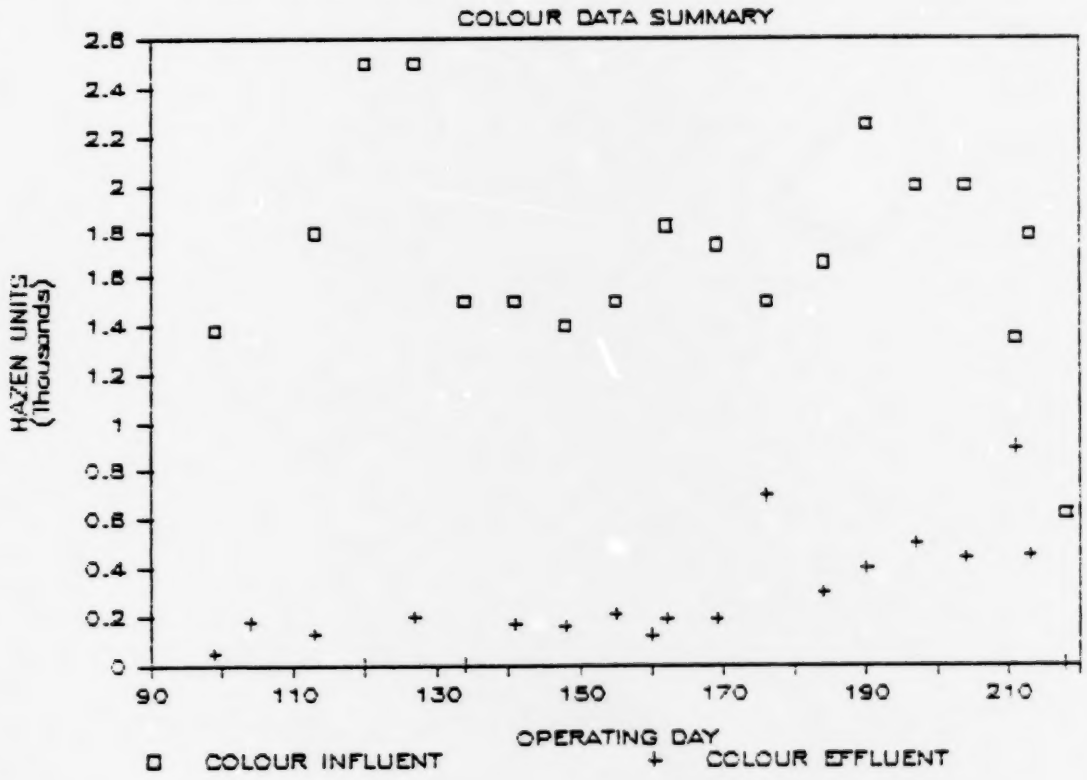
COLOUR DATA SUMMARY
HAZEN UNITS (thousands)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
90
110
130
150
170
190
210
OPERATING DAY
COLOUR INFLUENT
COLOUR EFFLUENT

FIGURE 6

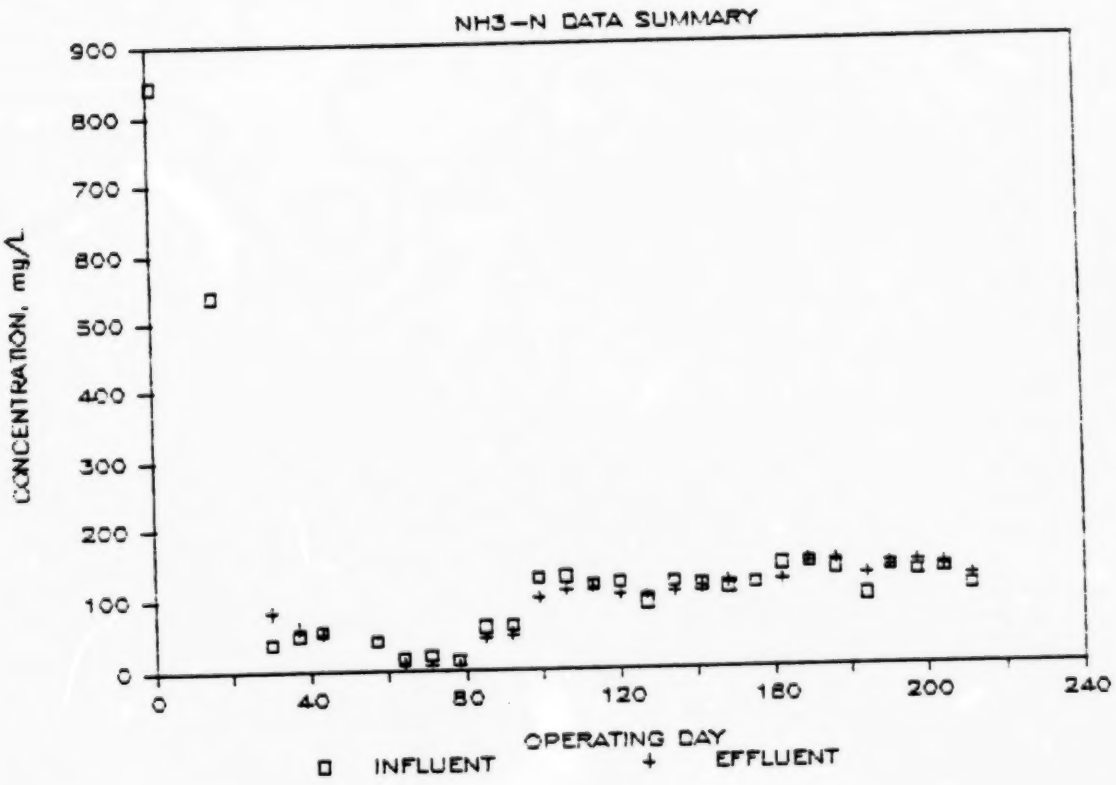
NH3-N DATA SUMMARY
CONCENTRATION, mg/L
900
800
700
800
500
400
300
200
100
0
0
40
80
120
160
200
240
OPERATING DAY
INFLUENT
EFFLUENT

FIGURE 7

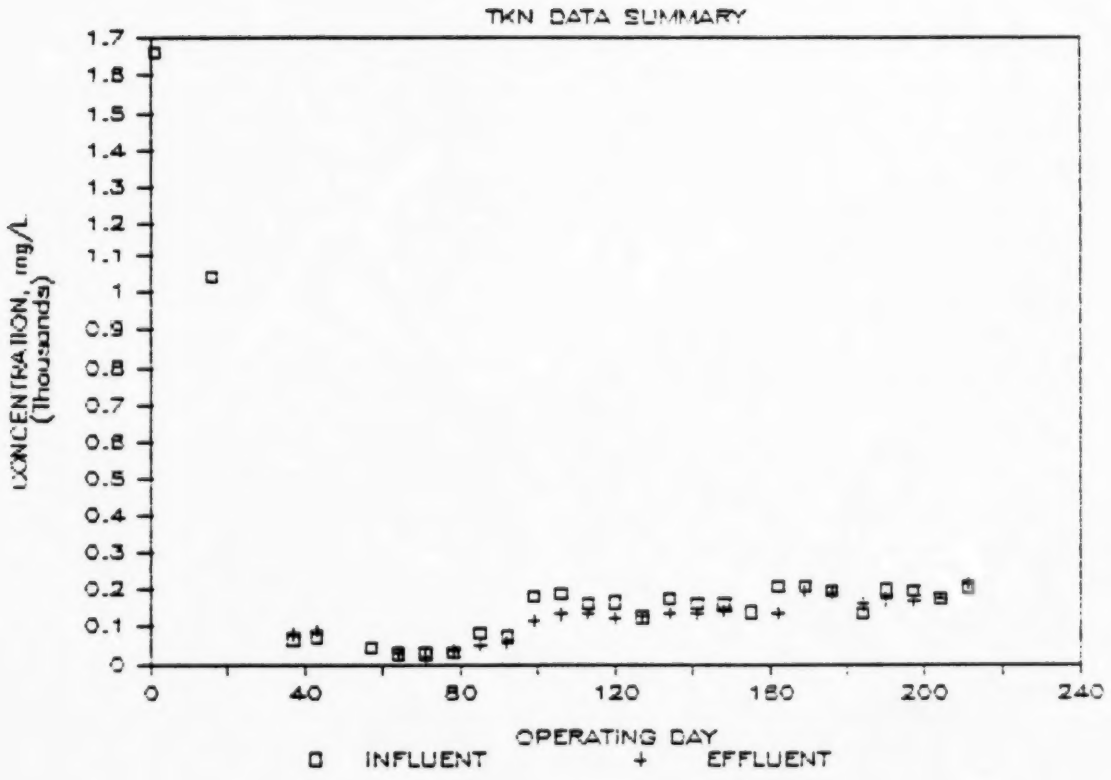
TKN DATA SUMMARY
CONCENTRATION, mg/L (Thousands)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
40
80
120
160
200
240
OPERATING DAY
INFLUENT
EFFLUENT

FIGURE 8

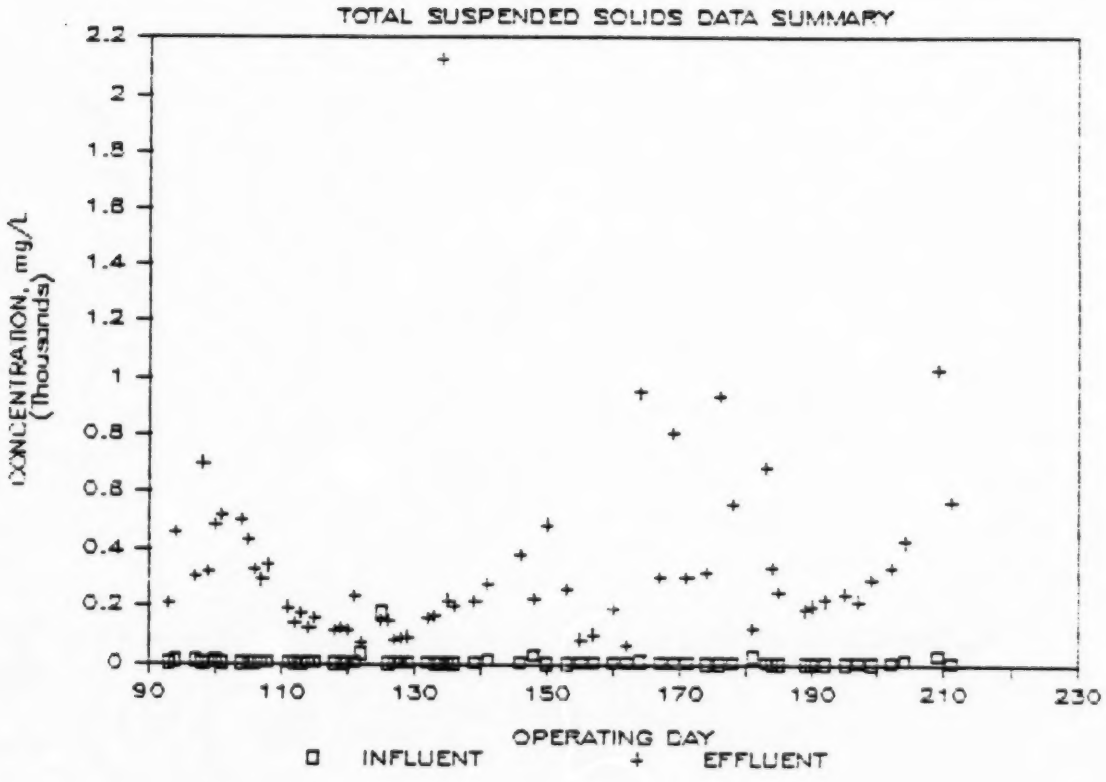
TOTAL SUSPENDED SOLIDS DATA SUMMARY
CONCENTRATION, mg/L (Thousands)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
90
110
130
150
170
190
210
230
OPERATING DAY
INFLUENT
EFFLUENT

FIGURE 9

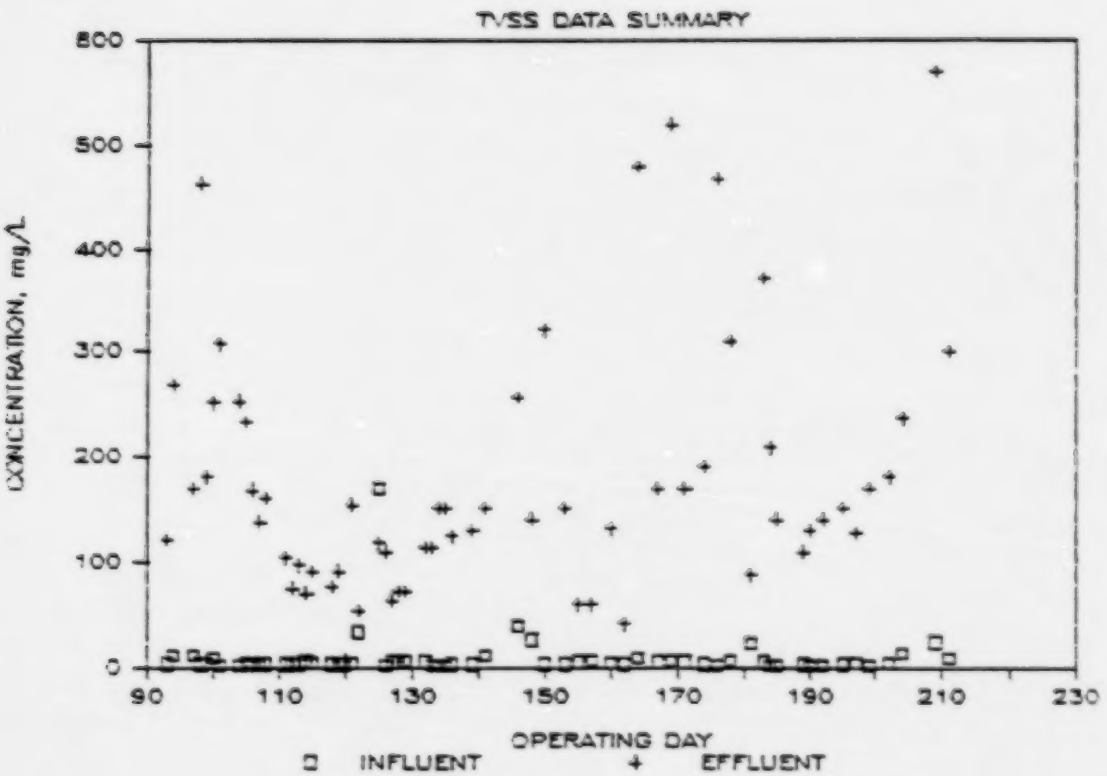
TVSS DATA SUMMARY
CONCENTRATION, mg/L
800
500
400
300
200
100
0
90
110
130
150
170
190
210
230
OPERATING DAY
INFLUENT
EFFLUENT

FIGURE 10

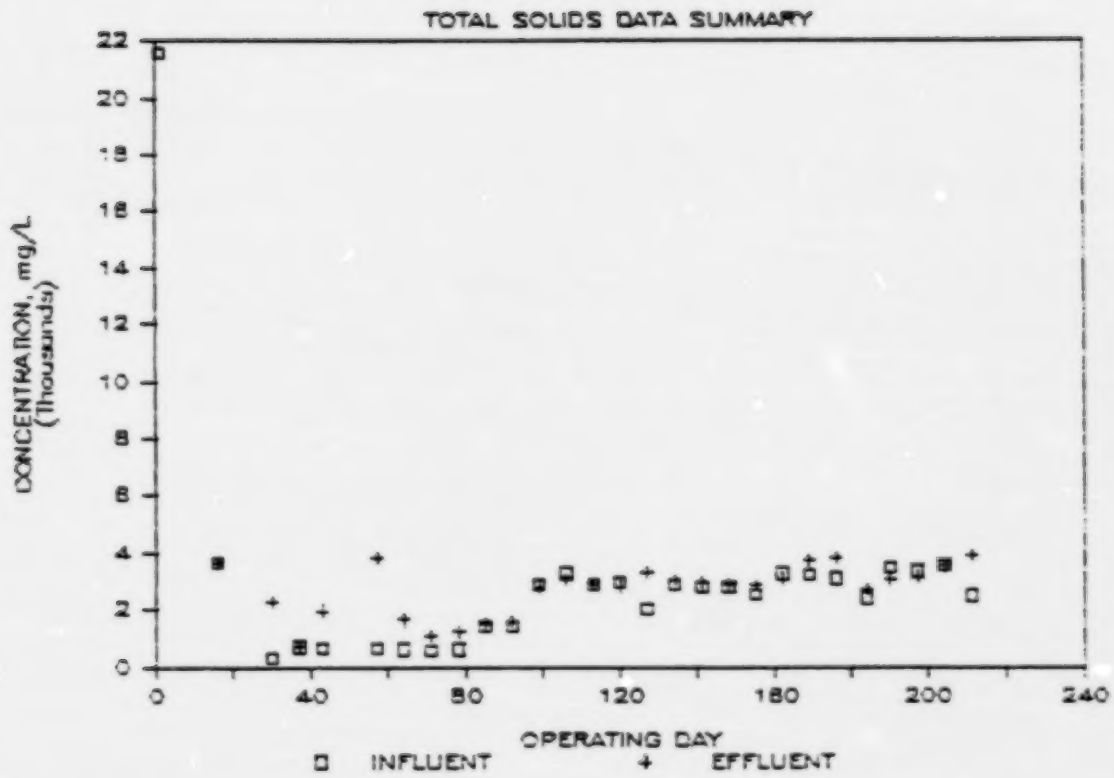
TOTAL SOLIDS DATA SUMMARY
CONCENTRATION, mg/L (Thousands)
22
20
18
16
14
12
10
8
6
4
2
0
0
40
80
120
160
200
240
OPERATING DAY
INFLUENT
EFFLUENT

FIGURE 11

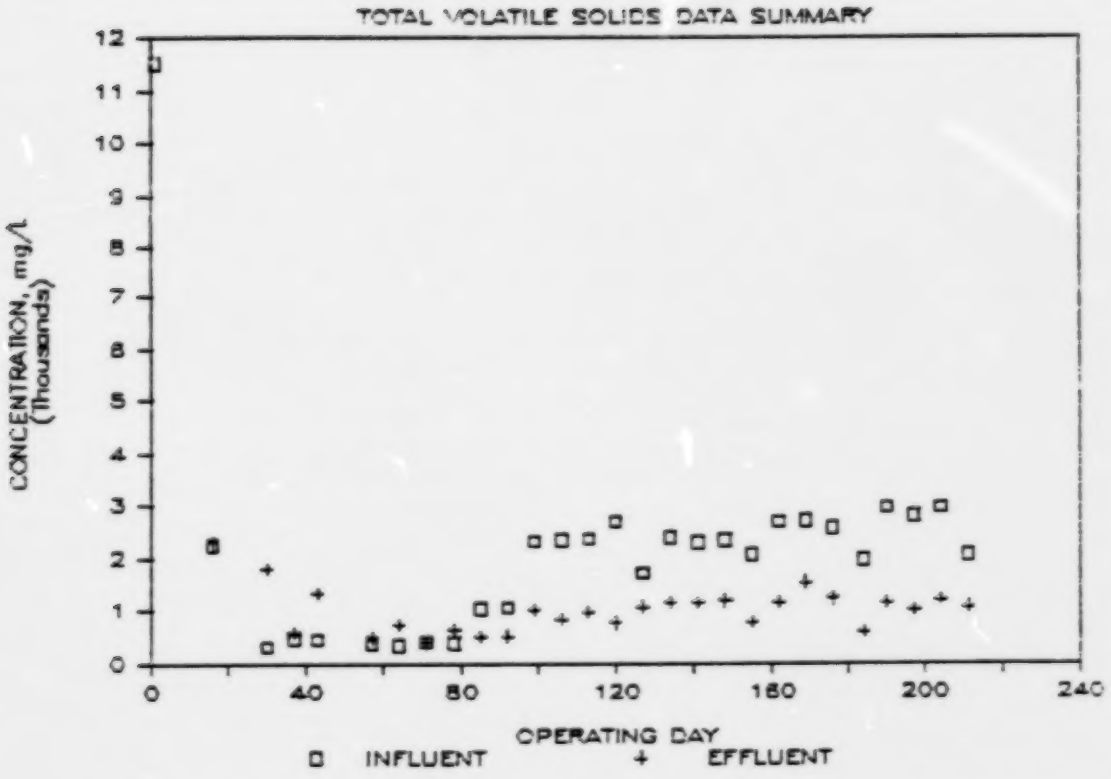
TOTAL VOLATILE SOLIDS DATA SUMMARY
CONCENTRATION, mg/l (Thousands)
12
11
10
9
8
7
6
5
4
3
2
1
0
0
40
80
120
160
200
240
OPERATING DAY
INFLUENT
EFFLUENT

FIGURE 12

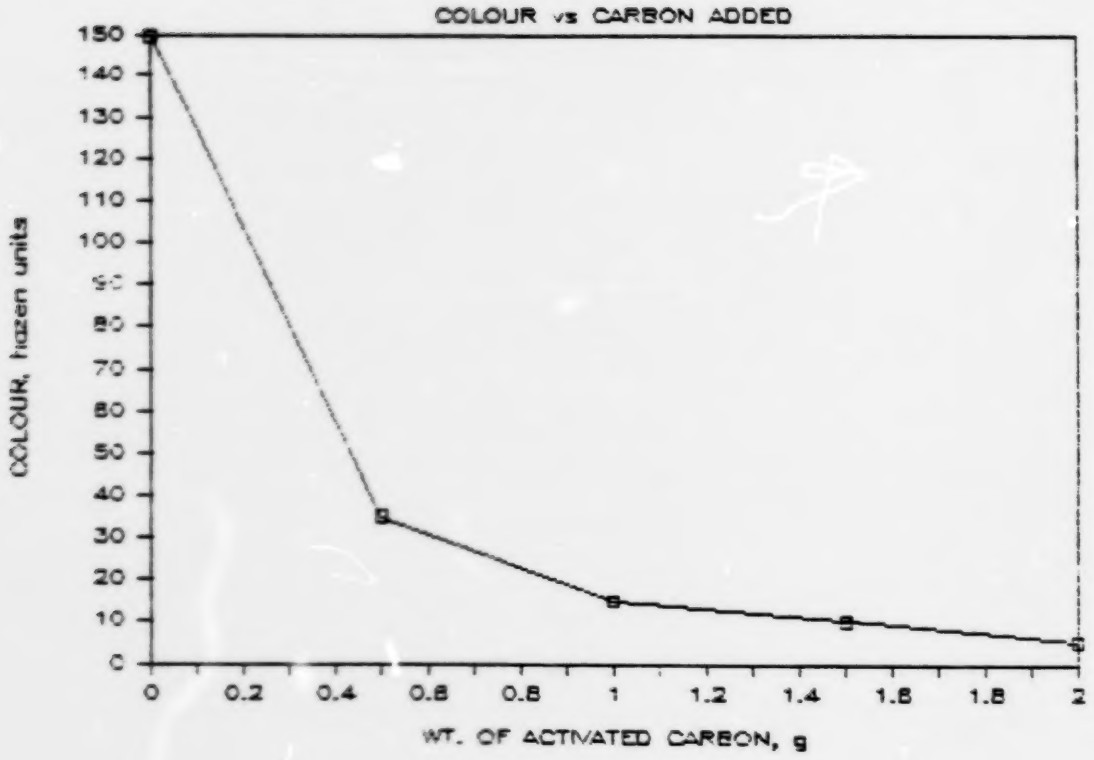
COLOUR vs CARBON ADDED
COLOUR, hazen units
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
WT. OF ACTIVATED CARBON, g

FIGURE 13

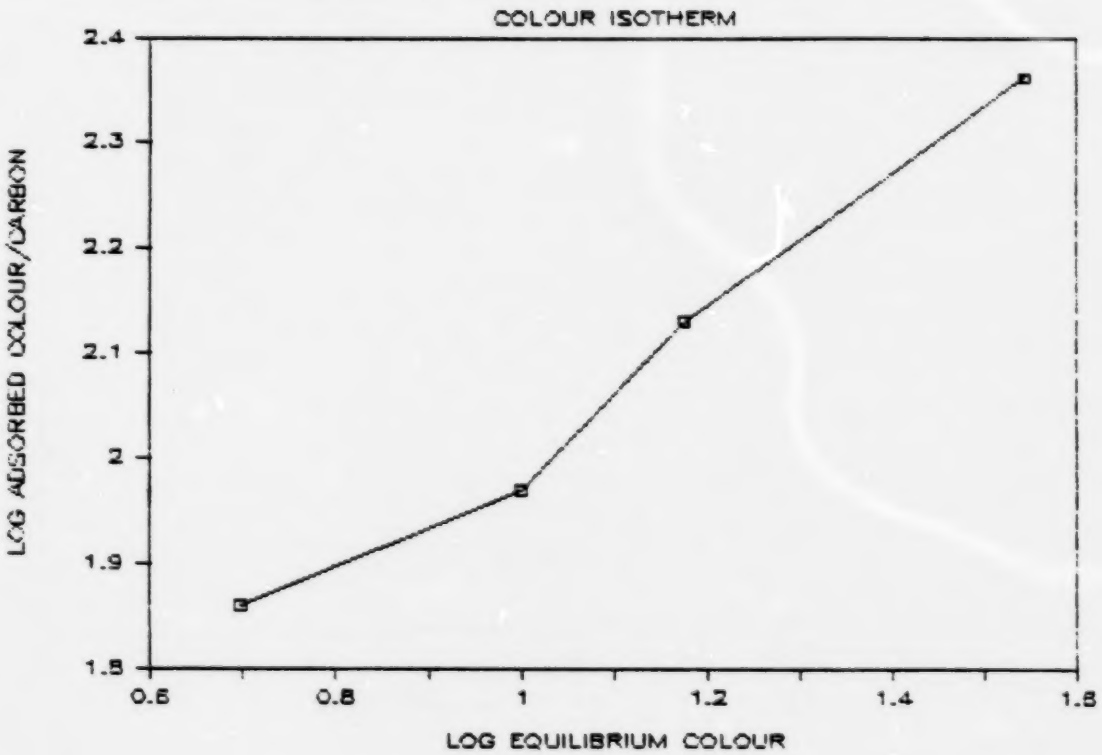
COLOUR ISOTHERM
LOG ADSORBED COLOUR/CARBON
2.4
2.3
2.2
2.1
2
1.9
1.8
0.6
0.8
1
1.2
1.4
1.6
LOG EQUILIBRIUM COLOUR

TABLE 4 - Gas Analysis

	Average Results %
CH_4	66.8
O_2	1.0
N_2	3.1
CO_2	25.5
H_2	0
CO	0

TABLE 5 - Colour Adsorption Results

Activated Carbon g	Equilibrium Colour Hazen Units
0	150
0.5	35
1.0	15
1.5	10
2.0	5

TABLE 6 - Ammonia Stripping Results

	g/L*	pH	% Ammonia Removal
g/L Constant	6.6	8.0	19
	6.6	8.5	28
	6.6	9.0	42
	6.6	10.0	92
pH Constant	0.9	8.0	6
	1.6	8.0	14
	3.0	8.0	13
	3.4	8.0	23
	6.6	8.0	19
	12.2	8.0	16

*Molar ratio of nitrogen gas and ammonia solution

7. DISCUSSION

7.1 Start-Up

Start-up of the anaerobic fluidized bed included the use of a decreasing proportion of municipal anaerobic digester supernatant and methanol, and an increasing proportion of wet oxidized peat filtrate. Hence, influent characteristics varied over the first 93 days of operation. Several process upsets were experienced during this period, further contributing to the varying performance, for example in terms of removal of COD and suspended solids.

7.2 Mesophilic Operation

The anaerobic fluidized bed was operated under a steady mesophilic temperature for a brief period (between days 93 and 104) before the system temperature was adjusted upwards to reach thermophilic conditions. COD loading rate over this period was approximately 3.9 kg COD/m^3.d. BOD and COD removal efficiencies were 67 and 61% respectively. These were the highest removal efficiencies reported during the project when treating wet oxidized peat filtrate. These values were substantially lower than the best performance reported in earlier work on anaerobic treatment of the same waste type using a plug flow horizontal anaerobic filter (Sheppard et al, 1982). Volatile acid removal was also low (38%) and again represented the best performance for the project. The high concentration of BOD and volatile organic acids in the effluent indicated that biological treatment was not complete.

Average production of volatile suspended solids (an indication of biomass production) was 0.11 g VSS per g COD removed. Note that this and other estimates of the biomass yield are based on a short time period and conclusions based on this number should, therefore, be made with caution.

Colour removal was very substantial during this period of operation (96%).

Temperature Transition Operation

The operating temperature of the anaerobic fluidized bed was gradually increased between operating days 105 and 146, while COD loading rate was maintained at 4 kg COD/m^3.d. Treatment efficiency was decreased during this transition period. BOD and volatile organic acid removals reduced to 51% and 24% respectively. The drop in performance was particularly evident when the system temperature was increased from 45^{o}C to 48^{o}C (operating days 120 to 127).

Net volatile solids production also decreased during this period. Approximately 0.042 g VSS were produced per g COD removed.

7.3 Thermophilic Operation

The anaerobic fluidized bed was operated at similar loading rate as was employed during the mesophilic and transition temperature periods (3.9 kg COD/m^3.d) between operating days 148 and 160. BOD removal efficiencies were likely still reflecting the effects of adjusting temperature. Solids production was also low during this period (0.11 g VSS/g COD).

COD loading rate was increased during operating days 162 to 213. Performance during this period was marred by two process upsets around days 162 and 211. This caused, in part, average COD, BOD and colour removals to be fairly low, 54%, 59% and 75% respectively. During the period between operating days 183 and 204, COD, BOD and colour removal were fairly consistent and averaged 58%, 64% and 79% respectively.

Average volatile solids production between operating days 160 and 213 was 0.09 g VSS per g COD removed.

For the last 10 days of sampling (operating days 214 to 223), no wet oxidized peat filtrate was added to the fluidized bed. Samples were withdrawn to monitor the effect of extended biological treatment. COD and BOD removals (based on the concentrations of the last influent) reached 54% and 93% respectively. The final BOD of the fluidized bed contents was reduced to 123 mg/L. Effluent true colour intensity and volatile acid concentration decreased 31% and 38% respectively between operating days 211 and 218.

7.4 Colour Adsorption

Activated carbon adsorption tests of the fluidized bed effluent are summarized in Figure 12. This graph shows equilibrium true colour against amount of activated carbon added per 100 mL of solution. It illustrates that the activated carbon within the fluidized bed did not remove all the adsorbable colour producing compounds present. Figure 13 shows the amount of colour (Hazen units x litres) removed per gram of activated carbon versus equilibrium condition. In yielding a straight line, this log/log plot indicates that the adsorption phenomena followed the predictions of the empirical Freundlich isotherm equation.

The Freundlich isotherm equation has the following form:

$$\frac{X}{M} = K\, C^{1/n}$$

where,

C	=	equilibrium concentration, Hazen Units
M	=	mass of adsorbent, gms
X	=	mass of substance adsorbed, Hazen Units x Litres
K, n	=	constants

Results from the batch adsorption tests for the values of K and n were 2.52 and 0.618 for colour. The capacity of the activated carbon to adsorb colour active compounds in the effluent COD was approximately 86 Hazen Units x litres per gram of activated carbon at a typical effluent colour of 300 Hazen Units. This amount of colour active compounds passed through the activated carbon fluidized bed approximately every 11 days (based on an effluent flowrate and colour intensity of 15 L/d and 300 Hazen Units respectively.

These isotherm results indicate that the colour removal capacity of the activated carbon column was greatly extended. This extension was apparently due to biological conversion of adsorbed colour active compounds. The role of in-situ biological regeneration (or extension of useful adsorbent life) was further evidenced by the temporary increase in colour intensity reported after process upsets. Figure 5 shows dramatic increases in effluent colour following reductions in biological treatment efficiency around operating days 162 and 211.

7.5 Ammonia Stripping

The ammonia stripping program was undertaken in the last week and a half of the fluidized bed operation. The pH of the operating unit was raised to 8.0 and the temperature was maintained at 55°C. A nitrogen gas line was installed in the bed which would strip off the ammonia. The effluent gas passed through an impinger (which, otherwise, served as a gas trap) containing 1N H_2SO_4 which was analyzed for ammonia nitrogen. This test showed no significant ammonia stripping.

Bench scale tests were conducted for gas stripping of ammonia. The gas/liquid (G/L) ratio was set at 6.6 moles of nitrogen gas to 1 mole of water. The percent ammonia stripped from a 130 mg NH_3-N ammonia solution as noted in Table 6, indicated that, at a pH of 8, gas stripping

was inefficient. This, in turn, precluded the practical stripping of ammonia from the recycle stream or within the anaerobic fluidized bed without pH adjustment.

A second bench scale experiment was conducted using different g/L ratios and solution pH fixed (at pH 8). The column temperature was 53-54^{o}C. The results of stripping a 130 mg/L NH_3-N solution shown in Table 6 indicate that the test apparatus was restricted to g/L ratios below 6.6 to avoid mass transfer limitations.

8. CONCLUSIONS

1. Anaerobic treatment of wet oxidized peat filtrate was shown to remove up to 93% of BOD. The filtrate contained a high proportion of COD which was not degradable anaerobically.

2. The thermophilic and mesophilic anaerobic fluidized bed achieved moderate treatment efficiency. Sustained COD and BOD removal efficiencies were in the ranges of 55-60% and 60-65% respectively.

3. Colour removal from the filtrate was sustained throughout the test program. The adsorptive capacity of the carbon bed was greatly enhanced by in-situ biological regeneration.

4. Ammonia stripping of anaerobic filter effluent or recycle liquid was shown to be impracticable at a pH of 8 at 55^{o}C. Adjustment of pH to approximately 10 was required.

5. The anaerobic fluidized bed proved to be subject to process upsets due to power or ancillary equipment failure. Considerable operator intervention was required to maintain the system and to re-establish operation after upsets.

9. RECOMMENDATIONS

1. Alternative reactor designs to the anaerobic fluidized bed should be investigated to take advantage of the biological extension of adsorbent capacity, while improving on process reliability, biomass retention and treatment efficiencies.

2. The chemical structure of colour active compounds present in wet oxidized peat filtrate should be established.

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